the experience of Barry Cunliffe and Leendart Louwe Kooijmans. It proposes to adopt new strategies in research and other spheres. If anything, the approach of the first Programme may have been too ambitious, with four major projects placing a considerable strain on financial and administrative resources. Two major themes are now being considered through studies of the current state of knowledge; these, on wetland settlement and on medieval rural settlement, will be published as the basis for research programmes to begin in 1998. Further geophysical survey and some limited excavation are also taking place at Tara.

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Archaeology and archaeometry: from casual dating to a meaningful relationship?

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Most archaeology and anthropology departments are grouped as Humanities or as Social Sciences in university organizations. Where does that place the archaeometrists who approach the materials with the methods of physical and biological sciences? And where does it place the archaeologists themselves — especially when archaeometric studies have a large place in contract archaeology?

The 1981 Brookhaven round table *Future Directions in Archaeometry* saw archaeologists and archaeometrists engage in pointed criticism of each other (Olin 1982). Frank Hole's contribution ('Finding problems for all the solutions') expressed the feeling of many of the archaeologists present that much archaeometric research served no demonstrable archaeological purpose, while many archaeometrists expressed frustration with archaeologists' ignorance of the methods and limitations of archaeometry.

In 1981 there were very few individuals with training in both archaeology and in the physical or natural sciences, leading to the lack of mutual understanding that is evident in the Brookhaven proceedings. The panellists at Brookhaven were acutely aware of this division, but could not agree on a remedy. Some were in favour of training students in both archaeology and archaeometry; others feared that this would produce what one speaker called 'half-baked archaeologists who know a little bit of science' (Olin 1982: 71). Sixteen years on this fear seems to have been unjustified. Scientists without archaeological training still play an essential role in the development of techniques. But there are now a substantial number of the 'brokers' for whom Frank Hole called in 1981 — those with enough archaeological training to spot meaningful research problems, and enough scientific training to pursue them. A good example of this is the use of $^{13}C/^{12}C$ ratios

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to infer prehistoric diet. Radiocarbon scientists had known since the late 1960s that the bimodal distribution of carbon isotope ratios in plants reflected different mechanisms of photosynthesis, but it took an archaeometrist trained in both archaeology and radiocarbon dating to realize the implications for the reconstruction of past diets and of the spread of crop plants (Vogel & van der Merwe 1977).

Archaeology and archaeometry in 1997

The integration of archaeometry into archaeology varies by technique and by region. The duration of the relationship is clearly a major factor. Radiocarbon dating was rejected by many European archaeologists in the 1950s and 1960s, but few do so now. Archaeometallurgy came in for some harsh criticism at Brookhaven, but, at thirty-something, is now winning acceptance as a legitimate research specialty in archaeology. Molecular biology is a more recent arrival and is still trying to work out a meaningful relationship with archaeology.

Having overcome their intial reservations about each other, archaeologists and archaeometrists in some regions have been moving in together. This process is most advanced in Britain, where some archaeology departments, notably Bradford, Sheffield, Cambridge and Nottingham, have chosen to emphasize archaeometric research, and have made archaeometry a major focus of their curricula. Funding of archaeometric research and development has been moved to the Natural and Environmental Research Council (NERC). This bestowed formal recognition upon archaeometry as a legitimate branch of science and provides NERC-funded doctoral research studentships, which are essential for the continuing development of archaeometric techniques.

With the possible exception of Japan (see below) the relationship between archaeometry and archaeology in the rest of the world has not developed as far as in Britain. In France the separation of the research units of the CNRS from the universities creates problems in transferring new research skills into the education of archaeologists. In South Africa, as in France and Britain, archaeometry is recognized as a legitimate branch of science and is funded accordingly. At the University of Cape Town, as at Bradford and Sheffield, all archaeology students must take at least a survey course in archaeometry.

The major flaw in the French and South African systems is lack of continuity. Because funding is awarded to persons rather than projects, research units usually disappear if that individual retires, dies or accepts a job elsewhere. Archaeometry is even more fragile in nations such as Canada, Germany, Israel and Australia, where it enjoys no formal recognition. In Australia there are few courses taught in archaeometry but this there has nevertheless been a consistent flow of quality archaeometric research. Rhys Jones (pers. comm. to SMMY 1995) suggests that this reflects the nature of Australian archaeology, in which questions of chronology, palaeoenvironment and provenance — the natural terrain of archaeometry — loom large.

There are no courses in archaeometry and few laboratory facilities on the African continent outside South Africa. Under these circumstances it is suprising that much good interdisciplinary work has been done. Childs (1994: 9) attributes this very largely to the influence of a few archaeologists, who recognized the dependence of African archaeology upon archaeometry and actively sought collaboration. In Israel, by contrast, archaeometry has had a mixed reception. Archaeometry is well integrated into prehistoric archaeology, as in recent excavations at Kebara and Hayonim caves (Weiner *et al.* 1995), but archaeologists of the Iron Age and later historic periods are generally indifferent to archaeometry (Goldberg 1988; J. Gunneweg pers. comm. to SMMY 1995).

In Canada, Germany, Australia and most other nations that do not recognize archaeometry as a legitimate branch of science, most archaeometrists outside dating laboratories are renegade scientists or engineers. They get little credit for this in their home departments, and are never replaced with archaeometrists on retirement (as has happened at the University of Toronto, once a major centre of archaeometry).

The main conclusion that we draw from this overly compressed review is that while it is possible to do good archaeometric research in many settings — some highly structured, some informal — it is difficult to maintain continuity or to educate the future producers and consumers of archaeometry without formal structure. With this in mind we turn to the current relationship between archaeology and archaeometry in the USA, the main focus of our concern.

fiscal year	funds disbursed $	grants for dating $	dating as % of funds disbursed
1986	680,358	550,538	81
1987	896,101	643,974	72
1988	914,859	559,256	61
1989	891,918	416,337	47
1990	926,555	454,970	49
1991	1,019,000	691,836	68
1992	1,015,338	580,170	57
1993	928,793	574,301	62
1994	694,513	542,600	78

TABLE 1. *Funds disbursed 1986–1994 by the annual archaeometry competition of the Anthropology Program, National Science Foundation. (Figures calculated by DJK from data supplied by John Yellen.) Different totals would result if we listed grants* awarded *each year, since many awards are disbursed over two or three years.*

Archaeology and archaeometry in the USA

Demand for archaeometric services in the USA has soared since 1981, almost entirely because of the growth of Cultural Resource Management (CRM). Federal funding for academic archaeology (from the National Science Foundation (NSF) and the National Endowment for the Humanities) has declined in real dollars since 1981, but has been more than offset by Federal expenditures for CRM through the National Park Service, the Forest Service, the Bureau of Land Management, the Bureau of Reclamation and the Department of Defense. We have found no national estimate of annual CRM spending on archaeometric services, but some indication of its magnitude may be gleaned from estimates (obtained from sources in CRM) that annual spending on CRM archaeology in Arizona alone exceeds $30 million, of which at least 25% is spent on archaeometric services. For comparison, the National Science Foundation's entire annual budget for archaeometry averages $1 million (TABLE 1), with perhaps another $1 million worth of archaeometric services purchased annually by archaeologists with grants from the NSF archaeology programme.

Does this mean that the meaningful relationship advocated at Brookhaven has come to pass? We think not, as do other recent writers on this subject (e.g. Sabloff 1991; Dunnell 1993; de Atley & Bishop 1991; van Zelst 1991). Dunnell castigates archaeometrists for irrelevance; van Zelst denounces archaeologists as unwilling to learn what archaeometry can and cannot do; de Atley & Bishop blame academic archaeologists for not making archaeometry part of the curriculum, and both they and Sabloff argue that the institutional structure of American universities discourages interdisciplinary ventures.

Are archaeometrists to blame?

We beg to differ from Dunnell. Proceedings of archaeometric symposia (particularly those of the Materials Research Society) do contain some papers that identify no archaeological problem, but most of these are the bastard offspring of scientists who find a brief fling with the past a break from their usual routine. This is not archaeometry; in 1997 a scientist must have some lasting degree of commitment to archaeology to be called an archaeometrist.

The archaeometric community is certainly not blameless. There are still major problems with quality control in archaeometry, and chronic underfunding of research and development has meant that many methods have never been properly evaluated. But in general we think that archaeometrists have made a sincere effort to overcome the criticisms levelled at Brookhaven. Summer courses like those of the Center for Materials Research in Archaeology and Ethnography (CMRAE) at MIT, and internships at centres such as the Smithsonian Institution's Conservation Analytical Laboratory and the University of Missouri Research Reactor (MURR) have trained hundreds of young archaeologists in interdisciplinary research. The Society for Archaeological Sciences has run annual reviews of selected topics at the Society for American Archaeology meetings. (These are inevitably poorly attended.) There have also been attempts to make complex archaeometric techniques more user-friendly (e.g. Stuiver & Reimer 1993).

What do American archaeologists know about archaeometry ?

While there are many examples of intelligent application of archaeometry to archaeological problems, we agree with van Zelst (1991) that far too many American archaeologists are poorly informed about archaeometry. Consider the case of radiocarbon dating. Both the first and second interlaboratory radiocarbon calibration rounds revealed an alarming lack of precision and accuracy (International Study Group 1982; Scott *et al.* 1990). In the second of these exercises, concluded in 1990, only 7 of the 38 laboratories that completed the round were able to demonstrate satisfactory accuracy and precision (Baxter 1990).

European archaeologists have been rightly critical of the lack of quality control in the radiocarbon community (e.g. Ottaway 1986; Baillie 1990), but American archaeologists have had almost nothing to say (Shott 1992 is a rare exception). What other population of consumers in America displays so little concern for the quality of the product that it purchases? This is casual dating indeed! Only 4 of the 38 laboratories participating in the second study were American. American archaeologists should pressure their laboratories to participate in international calibration projects and to disclose their performance. They should also ask radiocarbon laboratories to produce internal evidence of quality control, in the form of regular repeat analyses of samples of known age (e.g. Long 1990). The selection of the radiocarbon laboratory is the responsibility of the archaeologist alone, and only pressure from consumers will weed out the bad laboratories from the good.

Many other examples can be found. Archaeologists are now eager to undertake studies of past diets by chemical or isotopic techniques. Such studies should collect data on a broad spectrum of potential foods *before* attempting to interpret chemical data obtained on human bone (e.g. Keegan & de Niro 1988; Sealy & Sillen 1988). Unfortunately, as in provenience studies, it is too often the case that archaeological samples are run without adequate study of chemical or isotopic variation in potential sources.

The development of rapid methods of chemical analysis has made provenience analysis a routine part of the archaeological tool-kit, but these methods are not always well used. Far too many recent ceramic provenience studies rely for their archaeometric component entirely upon statistical analysis of chemical data. It is often assumed that distinct clusters in such data represent different loci of production, but such an inference can only be considered secure when multiple lines of evidence (chemistry, mineralogy of inclusions, regional and local geology, form, decoration and paste colour) converge, as in Triadan's recent study of the distribution of White Mountain Redware in Arizona (Triadan 1997).

These examples (and there are many others) suggest that many archaeologists are too complacent about the quality of archaeometric data, and do not appreciate the importance of variation in natural systems, whether geological or biological.

The influence of CRM on archaeometry in the USA

Although there is much excellent interdisciplinary work in CRM, there is also also much abuse of archaeometry in this setting. The main culprits are inflexible contracts that specify the analyses to be undertaken even before the sites have been excavated. This checklist approach to analysis frustrates many CRM archaeologists of our acquaintance, wastes public and private funds, and has driven demand for certain techniques beyond the supply of suitably trained and experienced analysts.

For example, demand for the established methods of ceramic petrology and neutron activation analysis (INAA) far exceeds analytical capacity. But peer pressure or contractual obligations force archaeologists to undertake ceramic provenience studies, and many have turned to inexperienced analysts or to unproven techniques such as 'weak acid extraction' inductively-coupled plasma (ICP) spectrometry (Burton & Simon 1993). Reviewers of the paper (including one of the present authors) noted potentially serious problems with this new technique, but thousands of archaeological samples, most from CRM projects, had already been analysed by this technique before controlled comparisons of weak-acid ICP data with INAA and thin-section petrography were published (Neff *et al.* 1996; Triadan 1997). These studies conclude that the weak-acid ICP data are incompatible with those produced by INAA, petrography and with archaeological classifications by form, decoration and paste. The technique is not therefore a reliable means of inferring ceramic provenience.

CRM archaeology in the USA is a fiercely competitive business. There is no time for the controlled experiments or for the additional checks that academic archaeometrists might consider desirable; if these are not specifically included in the Request for Proposals, then they are not likely to be included in bids submitted by CRM companies. In the American southwest, for example, most CRM projects commission large numbers of archaeological pollen analyses, yet many skimp on the collection of the modern pollen samples that are needed to interpret the prehistoric pollen spectra. Much of the data produced cannot be used in comparative work because of lack of consistency in analysis and reporting (Suzanne Fish pers. comm. to DJK 1994).

The responsibility for ensuring that archaeometric work within CRM projects is not wasted lies squarely with those who write the Request for Proposals and with the State Historic Preservation Officers (SHPOs) who must approve CRM research design at the state level. Those who set policy for archaeology within the various Federal agencies should also set uniform standards for the purchase, quality and reporting of archaeometric work across the whole span of Federal archaeology. American archaeology may have something to learn in this respect from Japan, where systematic provision has been made for archaeometry within CRM and where uniform standards are set for analysis and reporting (Izumi Shimada pers. comm. to DJK 1997).

Who should pay for research and development in archaeometry?

Although the growth of CRM in the United States has fuelled demand for archaeometric techniques, CRM contributes little to fundamental research on archaeometric techniques. The only significant source of funding for this in the USA is the annual NSF Archaeometry competition, created in 1984

1 to provide core funding on a competitive basis to laboratories supplying archaeometric services; and
2 to fund research into new techniques.

This programme has succeeded in funding a wider range of archaeometric research than before (Yellen 1982; 1992), though grants to dating laboratories have accounted for between half and four-fifths of all expenditure in each year of the archaeometry competition (TABLE 1). Once other core support (mostly for neutron activation) is subtracted, the amount left for development of all other archaeometric techniques has has in recent years averaged around $300,000 per year, or about four to six research projects.

The lack of funding for research and development has led to techniques coming into wide use in archaeology before being properly researched. Stable carbon isotope analysis is a case in point. This has been highly succesful in tracing the adoption of C4 cultigens, such as corn, into C3 biomes such as eastern North America (Vogel & van der Merwe 1977) and the Amazon (van der Merwe et al. 1981) over the *longue durée*. Many archaeologists are trying to use it for finer-grained analysis, for example in trying to infer differences in diet within synchronic populations. But it is not yet understood from what components of the diet bone collagen and bone apatite are formed (Sillen *et al.* 1989); this is being studied by controlled feeding of rats and pigs (supported by the NSF Archaeometry). This may seem a long way from archaeology — but is absolutely necessary if isotopic reconstructions of diet are to be scientifically defensible.

Inferences about prehistoric diets based upon chemical analysis of archaeological bone are on much shakier ground. Thousands of bones have been analysed in the last 25 years, but recent reviews of the nutritional and physiological literature (Ezzo 1994a; 1994b) show that, except for strontium and barium, there is little experimental evidence that the concentration of the chemical elements in bone correlates with their abundance in the diet.

Although other divisions of NSF, such as earth sciences and cell biology, support fundamental research on techniques, funds to adapt and expand these for archaeology must usually come from the NSF budgets for archaeology and archaeometry. There is clearly not enough money in this system at present to fund development of all the techniques that have potential for archaeology. Other Federal agencies are however major consumers of archaeometric services, and it is clearly in their own self-interest to help fund development of archaeometric research that is relevant to their own interests.

Archaeometry in the education of archaeologists

How has education changed to reflect the greatly increased role of archaeometry within archaeology ? As noted above, some universities outside the USA (Bradford, Sheffield, Cape Town) have chosen to offer a concentration in the area of archaeometry, and require all students to study it. To our knowledge, only two American universities (Southern Methodist University and Boston University) require all graduate students in archaeology to take at least a survey course in archaeometry. At least a dozen other American universities offer such a course, but it is not mandatory. Our experience with survey courses on archaeometry at the University of Arizona and at Harvard University has been that fewer than one in ten archaeology graduate students elect to take it.

We believe that a course that concentrates on making archaeologists educated consumers of archaeometry should be required of all archaeologists. Almost all archaeological projects now include an archaeometric component, but the supply of experienced archaeometrists has not increased in proportion to the demand for their services. Increasingly archaeologists will be forced to commission analyses on a fee-for-service basis from remote laboratories, and to deal with problems of experimental design, sampling and interpretation on their own. Archaeologists also have to be able to assess the use of archaeometry in archaeological literature.

It is obviously preferable to work with an experienced archaeometrist, which brings us to the problem of the acute shortage of trained archaeometrists in the USA. The time has come for one or more universities to introduce a graduate degree in archaeometry/archaeological science. The appropriate model for this is the programme at the University of Bradford, where students are put through a curriculum that integrates archaeological and archaeometric training.

Conclusion and recommendations

We conclude that some progress has been made since Brookhaven, but that archaeology and archaeometry are still poorly integrated. The two fields are best (though not perfectly) integrated in Britain; the USA lags a long way behind. We believe that the major problems hindering the closer union of the two fields in America are the lack of attention paid to archaeometry in the education of archaeologists and archaeometrists, and the indequate funding of research on archaeometric technique and development.

Our recommendations for the USA are:

1 that all archaeology students should take at least a survey course in archaeometry;
2 that urgent measures be taken to increase the numbers of trained archaeometrists, and to identify and support key centres for archaeometric services; and
3 that additional funds for research and development of archaeometric techniques be raised by harvesting a small portion of current CRM archaeology spending by Federal agencies.

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